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RESEARCH MEMORANDUM

INVESTIGATION OF ADJUSTABLE SUPERSONIC INLET IN COMBINATION WITH J34 ENGINE UP TO MACH 2.0

By J. C. Nettles and L. A. Leissler

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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INVESTIGATION OF ADJUSTABLE SUPERSONIC INLET IN COMBINATION WITH J34 ENGINE UP TO MACH 2.0

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SUMMARY

An annular nose inlet equipped with a remotely controlled translating spike and variable bypass was investigated in the Lewis 8- by 6-foot supersonic wind tunnel. The inlet performance was studied both with the air flow controlled by an operating J34 engine and with the engine simulated by a choked plug. The configuration was investigated at supersonic Mach numbers from 1.7 to 2.0 and at subsonic speeds of approximately Mach zero and 0.6.

The results of the investigation indicated that with the engine operating at maximum rpm the diffuser could be maintained critical by use of either the bypass or the translating-spike technique throughout the supersonic Mach number range investigated. With this particular design for spike translation, the inlet had high pressure recovery for all spike positions where the conical shock intercepts the cowl lip. The highest pressure recovery was observed for the condition where the oblique shock was the farthest ahead of the lip. In general, the engine exhibited a stabilizing influence on the inlet. The range of unstable operation and the observed intensity of pulsing were less with the actual engine than with the exit plug. The engine could be operated through certain zones of instability without difficulty, whereas with the choked exit the amplitude of pulsing built up to a violent level when a traverse through the pulsing zone was attempted.

INTRODUCTION

Operation of a turbojet engine over a range of supersonic flight speeds requires that the inlet incorporate an independent means of air flow control in order to maintain pressure recovery and to avoid subsonic additive drag penalties (ref. 1). One method of providing variable air flow is by means of a bypass through which air not required by the engine can be discharged (ref. 2). Variable air flow can also be obtained in a conical inlet by translating the spike to control the amount of air taken in at the diffuser cowl (ref. 3).

An additional aspect of the combination of diffuser and turbojet engine is the possibility of an influence of the engine on the flow stability characteristics of the diffuser. The effective storage volume of the engine, the friction damping developed in the compressor, and the pressure-rise - volume-flow and surge characteristics of the compressor itself all enter into the dynamic flow system.

In order to obtain an experimental evaluation of these various problems, a translating cone inlet equipped with a bypass arrangement was constructed for a J34 engine. Pressure recovery and matching characteristics of the inlet-engine combination are presented for various spike positions and bypass openings for the range of Mach numbers up to 2.0. The investigation was conducted in the Lewis 8- by 6-foot tunnel during March, 1954.

SYMBOLS

The following symbols are used in this report:

A flow area, sq ft

A_c cowl-inlet capture area

A_r reference area, defined by compressor-inlet diameter

D_e hydraulic diameter at cowl entrance, $\frac{4A_1}{\text{wetted perimeter}}$

M Mach number

M_D Mach number at which conical shock intersects cowl lip

P total pressure, abs

P_i local total pressure, abs

W_2 air flow measured at station 2, lb/sec

W_3 air flow measured at compressor face, lb/sec

N engine rotational speed

N_r rated engine rotational speed, 12,500 rpm

T total temperature, abs

δ P/NACA standard sea-level absolute pressure

θ T/NACA standard sea-level absolute temperature

Subscripts:

x axial station

0 free stream

1 cowl inlet

2 ahead of bypass

3 compressor face

Physcial constants:

$A_c = 1.658$ sq ft

$A_r = 2.41$ sq ft

$A_1 = 1.03$ sq ft at $M_D = 2.4$, and 1.38 sq ft at $M_D = 1.58$

$A_2 = 1.52$ sq ft

$A_3 = 2.05$ sq ft

$D_e = 7.29$ in. at $M_D = 2.4$, and 11.05 in. at $M_D = 1.58$

APPARATUS AND INSTRUMENTATION

Description of Model

The general layout of the nacelle with the J34 engine and the air inlet are shown in figure 1. The normal complement of engine accessories was removed in order to achieve a minimum of frontal area. The blockage area of the nacelle-strut combination was further reduced by mounting the nacelle off the tunnel center line. Fuel supply, oil supply, and oil scavenge lines were run through the support strut to pumps located exterior to the tunnel. The engine tail pipe was cylindrical to 1 diameter downstream of the turbine tail-cone fairing where it was terminated by a convergent nozzle. The starter was retained on the engine, and a pulse generator type of tachometer pickup was incorporated in the starter drive to permit measurement of the engine revolutions.

A configuration consisting of a front compressor housing and an internally mounted variable-area plug was installed with the diffuser for one series of runs in order to establish the stability limits of the diffuser with a configuration that was typical of a cold-flow wind-tunnel model. This configuration also permitted a calibration to be made for the diffuser-air-flow measuring stations by using the choked-plug technique.

Inlet Design

The inlet was designed for translation of the cone as suggested in reference 3. A combination of a 17° internal cowl angle and a 25° half-angle cone made it possible to contour the subsonic diffuser such that an area variation essentially equivalent to a 6° total-angle cone was obtained at the forward spike position and internal contraction did not occur at the aft spike position. The forward spike position would be a design in which the conical shock intersects the cowl lip at a Mach number of 2.4, whereas for the aft spike position the shock intersection would occur at a Mach number of 1.58.

The centerbody contour included a cylindrical section in the vicinity of the support struts. A telescope joint at this point allowed the front section to be moved relative to the rear section. Remote operation of the cone position was accomplished by a screw jack mounted within the centerbody. The area variations for the forward and aft spike positions are given in figure 2. The 6° area variation was chosen on the basis of the information presented in reference 4, which indicates that this configuration has a strong tendency to buzz in the subcritical region and therefore would emphasize the effect of coupling an engine to the diffuser.

The bypass air was bled through the outer wall of the subsonic diffuser by a series of equally spaced longitudinal slots which were connected to the cavity between the diffuser wall and the nacelle skin. The flow of bypass air was controlled by a hinged door mounted in the nacelle skin and actuated by a screw jack located in the support strut.

The cowl-inlet capture area was purposely made larger than required for the engine air flow at a Mach number of 2.0 in order to permit investigation of the full range of flexibility afforded by the combination of translating spike and variable-area bypass.

Total and static pressures were measured ahead of the bleed slots and at the compressor face to determine pressure recovery, engine air flow, and diffuser air flow. Bypass air flow was determined by taking the difference between the two measuring stations. An additional determination of the air flow was made for the dummy engine runs by means of the plug area and the static pressure ahead of the plug. All diffuser pressures were measured by the NACA Digital Automatic Multiple Pressure Recorder. Pulsating flow was detected by a pressure transducer at the compressor inlet and by observation of the schlieren apparatus.

RESULTS AND DISCUSSION

The performance of the inlet with the variable-area plug configuration is presented in figure 3. In certain of the curves a zone of

instability followed by a region of stable flow is indicated rather than the usual minimum stable flow. A special technique was utilized to establish these ranges of stable flow. The outlet flow area was reduced to its minimum with the spike in its retracted position. The spike was then extended until either the flow became unstable or the desired spike position was reached. If the desired spike position could be set, the flow was then increased until pulsation was encountered. Both limits of the unstable zone were reproducible to essentially the same degree. The pulsation amplitude tended to build up rapidly with only slight changes of outlet area. An attempt to force the diffuser through a zone of instability at M_0 of 1.9 was terminated because of the violent pulsations encountered.

The corrective action that should be applied to avoid pulsing as far as the air flow is concerned depends on whether the unstable zone is approached from the high-air-flow or the low-air-flow condition. For the case where M_D is equal to or less than M_0, the pulsation can always be stopped, however, by retracting the spike. In other words, the corrective action for the translating spike is the same irrespective of how the condition was encountered.

The performance of the subsonic portion of the diffuser is presented in figure 4 for the condition of critical flow and with the spike positioned for the oblique shock to intersect the cowl lip for each free-stream Mach number. The total pressure entering the diffuser was computed in each case for supersonic compression through one oblique and one normal shock. The average Mach number of the flow entering the diffuser is noted at intervals along the curve. The entrance Mach number indicates that even though the performance of the subsonic diffuser is generally good the losses increase rapidly with increasing entrance Mach number. Inasmuch as translation of the spike also changes the subsonic diffuser area variation, there is undoubtedly a combined effect of Mach number and area variation on the observed losses.

The inlet in combination with the engine was operated at subsonic Mach numbers of essentially zero and 0.6. Data for these runs are presented in figure 5. Included on figure 5 are curves of the estimated performance of a sharp-lip inlet by the method of reference 5. In general, the performance of the inlet at the take-off condition was better than is predicted by the theory for sharp-lip cowls. The observed deviation between theory and experiment might well be caused by the fact that the cowl lip was not ideally sharp and also the forward velocity was not zero but was approximately 100 feet per second. The gain in performance due to opening the bypass was not as great as anticipated, however; this is probably caused by the relatively poor flow passage associated with the bypass system. At the 0.6 Mach number condition,

the performance with the bypass closed was slightly lower than estimated by theory. The curve for the bypass open shows that the bypass spills air that is needed by the engine and therefore the pressure recovery is reduced because of increased cowl-lip losses.

The supersonic performance of the inlet with the engine is presented in figure 6 with the bypass open and in figure 7 with the bypass closed. The air flow of figure 6 is measured ahead of the bypass slots and hence represents the flow into the diffuser. The pressure recovery was the value measured at the compressor face. Contours of engine air flow are included on figure 6 to indicate the air flow spilled by the bypass.

Comparison of figure 3 with figures 6 and 7 indicates little difference in general air flow and pressure recovery relations with and without the engine. However, with the engine, the diffuser could be operated over the range of air flow to higher Mach numbers without buzz. It was observed that the intensity of pulsing was generally lower with the engine than without. The engine could be forced through the unstable zone at M_0 of 1.9 without any apparent difficulty.

In line with the concept of retracting the spike to avoid pulsing flow, figure 6(d) shows that varying M_D from 1.9 (fig. 6(e)) to 1.86 was sufficient to eliminate the unstable zone. The inlet-engine combination had no subcritical stability at M_0 of 2.0 and M_D of 2.0. Retracting the spike to M_D of 1.92 reduced the instability to a narrow zone. Retracting the spike also reduces the pressure recovery; therefore, a balance between stable flow range obtained by spike retraction or by increasing the capacity of the bypass would have to be made on a thrust-minus-drag basis.

During the test at M_0 of 1.9 and M_D of 1.9 with the bypass closed, the engine was deliberately operated with pulsating flow. The data for this type of operation are included in figure 7(d). The engine did not exhibit any obvious reaction to the pulsating flow. It must be pointed out, however, that the reaction of the J34 engine to inlet pulsing may not be typical of an engine designed to operate closer to its compressor surge limits.

The radial-flow profiles for two conditions of inlet flow control at M_0 of 1.9 are presented in figure 8 for the diffuser station forward of the bypass slots and for the compressor face. In each case, the engine flow is the same, but the inlet flow is critical for a spike positioned at M_D of 1.9 with the bypass open and critical for a spike positioned at M_D of 2.4 with the bypass closed. Except for the obvious difference in pressure recovery, there is little difference in the compressor-face profiles for the two flow control methods.

A summary of the stability limits for the diffuser with and without the engine is presented in figure 9. In figure 9(a) the spike position M_D is fixed at 2.0. The effect of the engine was to increase the Mach number at which pulsing is first encountered and to reduce the extent of the unstable zone. Above M_0 of 1.8 the engine did not have any effect on the stable air flow limit when approached from the supercritical condition.

The minimum stable flow of the fixed spike position for M_D of 2.4 is presented in figure 9(b). The engine did not have any significant influence on the stability limits for this spike position at M_0 of 1.9 or 2.0. For the lower Mach numbers the minimum air flow obtained was limited by the engine rather than by stability of the inlet. The technique of establishing the existence of a zone of instability by retracting the spike and reducing the air flow could not be used to arrive at this spike position, because it was not possible to reduce the flow to a value low enough to permit traversing the spike through the M_D of 2.0 position.

The stability limits for variable-spike-type operation are presented in figure 9(c). For this case, the spike-position Mach number for conical-shock intersection of the cowl lip M_D is set equal to the equivalent free-stream Mach number M_0. Here again the effect of the engine on the stable range and Mach number at which pulsing is encountered is readily apparent. With the variable spike type of operation the stability limits are also markedly influenced by setting M_D slightly less than M_0, as was pointed out in connection with figures 6 and 7.

The engine-inlet match curves are presented in figure 10 for the M_0 range of 1.7 to 2.0, with an absolute engine rpm of 100 and 90 percent. The engine weight flow requirement is based on the equivalent rpm for 35,000-foot altitude and the pertinent M_0. The effect of sizing the inlet too large at M_0 of 2.0 is readily apparent. This could be corrected by reducing the cowl diameter the appropriate amount. Shifting the match point of the diffuser down to the engine requirement at M_0 of 2.0 would simply move all the diffuser curves down the same amount. Matching the engine at M_0 of 2.0, M_D of 2.0, and 100 percent rpm would result in supercritical inlet operation at M_0 less than 2.0 with a fixed spike position. The results with the spike at M_D at 2.0 are in substantial agreement with the predictions of reference 6.

Operation at the variable spike condition of M_D equal to M_0 would require subcritical operation of the inlet at M_0 less than 2.0. Finally, there is always a spike position between M_D equal to M_0 and M_D of 2.0 that will match the 100-percent-rpm engine air flow requirement at critical flow for the range of Mach numbers covered. If it is necessary to match the engine at 90 percent rpm, the spike would have to be extended a little further than the position at M_D of 2.4.

The range of air flow regulations available with the bypass system is presented in figure 11. The range of bypass air flow that can be attained is, of course, subject to a design choice of maximum flow area. Shifting the match point as in the previous case reveals that this particular bypass is adequate for matching the 100-percent-rpm requirement but will not handle sufficient flow to match the 90-percent-rpm requirement over the entire Mach number range.

The pressure recovery at critical flow for the various spike positions is presented in figure 12. This inlet had high pressure recovery for all spike positions where the conical shock intercepts the cowl lip. Pressure recovery of the inlet improved as the spike was moved forward. This is in contrast with the results obtained with the inlet of reference 3, which had a decreasing pressure recovery as the flow was controlled by advancing the spike because of an expansion ahead of the cowl entrance.

SUMMARY OF RESULTS

Based on the investigation of a translating-spike inlet with a variable bypass tested both with a variable exit plug and a J34 turbojet engine, the following results were obtained:

1. Either the translating spike or the bypass technique was satisfactory for matching the inlet and the engine over a range of supersonic Mach numbers without subsonic additive drag. The engine could be operated at maximum rpm over the usable tunnel Mach number range of 1.7 to 2.0.

2. The translating-spike inlet designed to avoid internal contraction and spike shoulder expansion at critical flow maintained high pressure recovery for all spike positions where the conical shock intercepts the cowl lip. Extending the spike to provide supersonic-flow spillage resulted in an increased pressure recovery.

3. In general, the engine exhibited a stabilizing influence on the inlet. The range of unstable operation and the observed intensity of pulsing was less with the actual engine than with the exit plug. The engine was operated through certain zones of instability without difficulty, whereas with the choked plug the amplitude of pulsing continued to build up if a traverse through the unstable zone was attempted.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, August 16, 1954

REFERENCES

1. Schueller, Carl F., and Esenwein, Fred T.: Analytical and Experimental Investigation of Inlet-Engine Matching for Turbojet-Powered Aircraft at Mach Numbers up to 2.0. NACA RM E51K20, 1952.

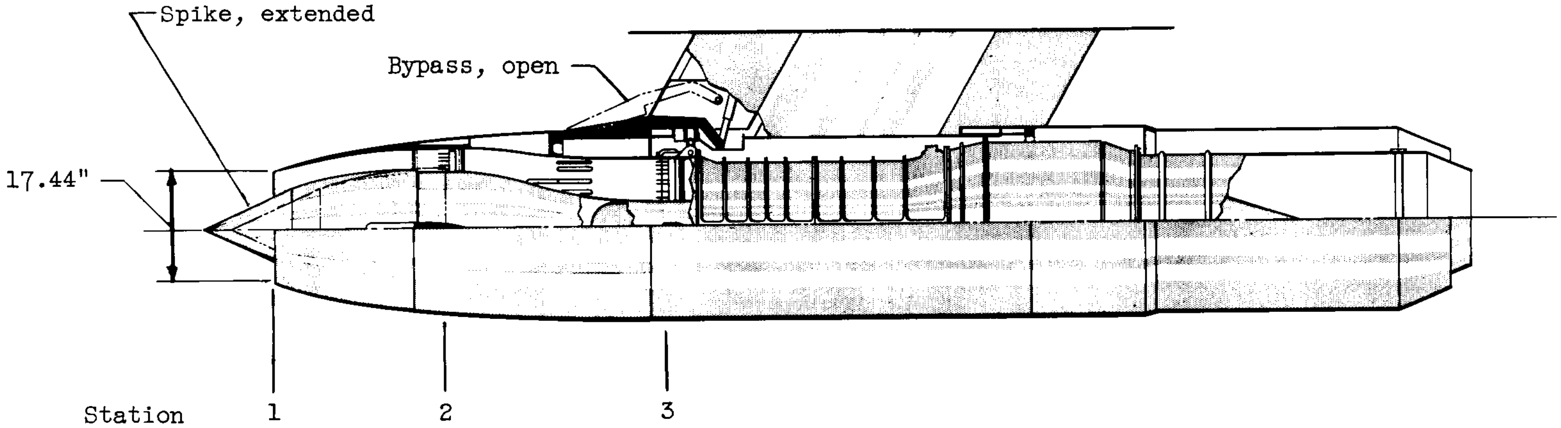
2. Allen, J. L., and Beke, Andrew: Force and Pressure Recovery Characteristics at Supersonic Speeds of a Conical Spike Inlet with Bypasses Discharging in an Axial Direction. NACA RM E52K14, 1953.

3. Gorton, Gerald C.: Investigation of Translating-Spike Inlet as Means of Mass-Flow Control at Mach Numbers of 1.5, 1.8, and 2.0. NACA RM E53G10, 1953.

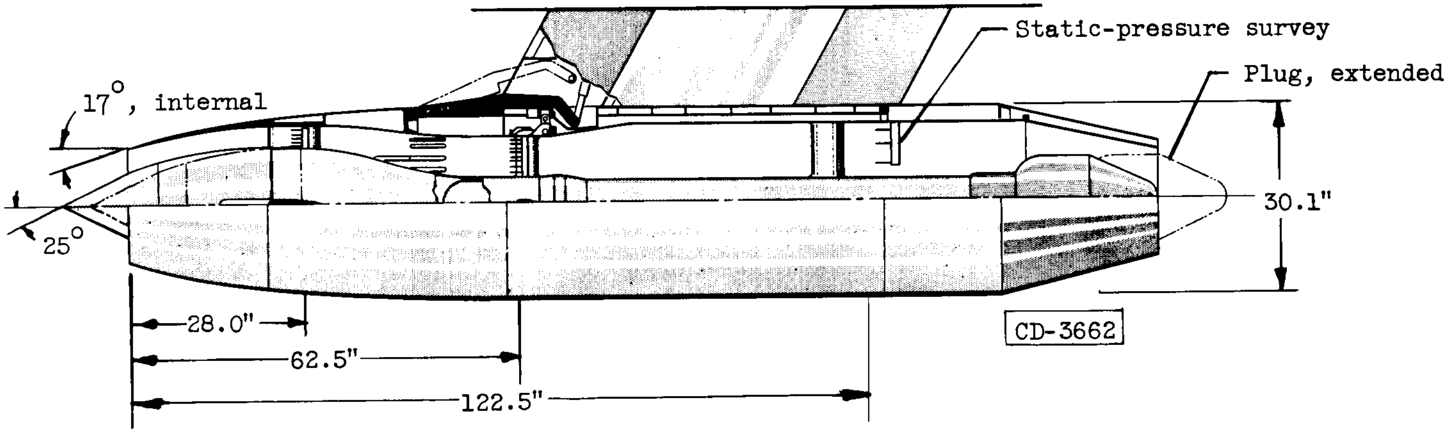
4. Nettles, J. C.: The Effect of Initial Rate of Subsonic Diffusion on the Stable Subcritical Mass-Flow Range of a Conical Shock Diffuser. NACA RM E53E26, 1953.

5. Fradenburgh, Evan A., and Wyatt, DeMarquis D.: Theoretical Performance Characteristics of Sharp-Lip Inlets at Subsonic Speeds. NACA TN 3004, 1953.

6. Wyatt, DeMarquis D.: An Analysis of Turbojet-Engine-Inlet Matching. NACA TN 3012, 1953.



(a) Nacelle installation with J34 engine.



(b) Nacelle installation with exit plug.

Figure 1. - Nacelle configurations.

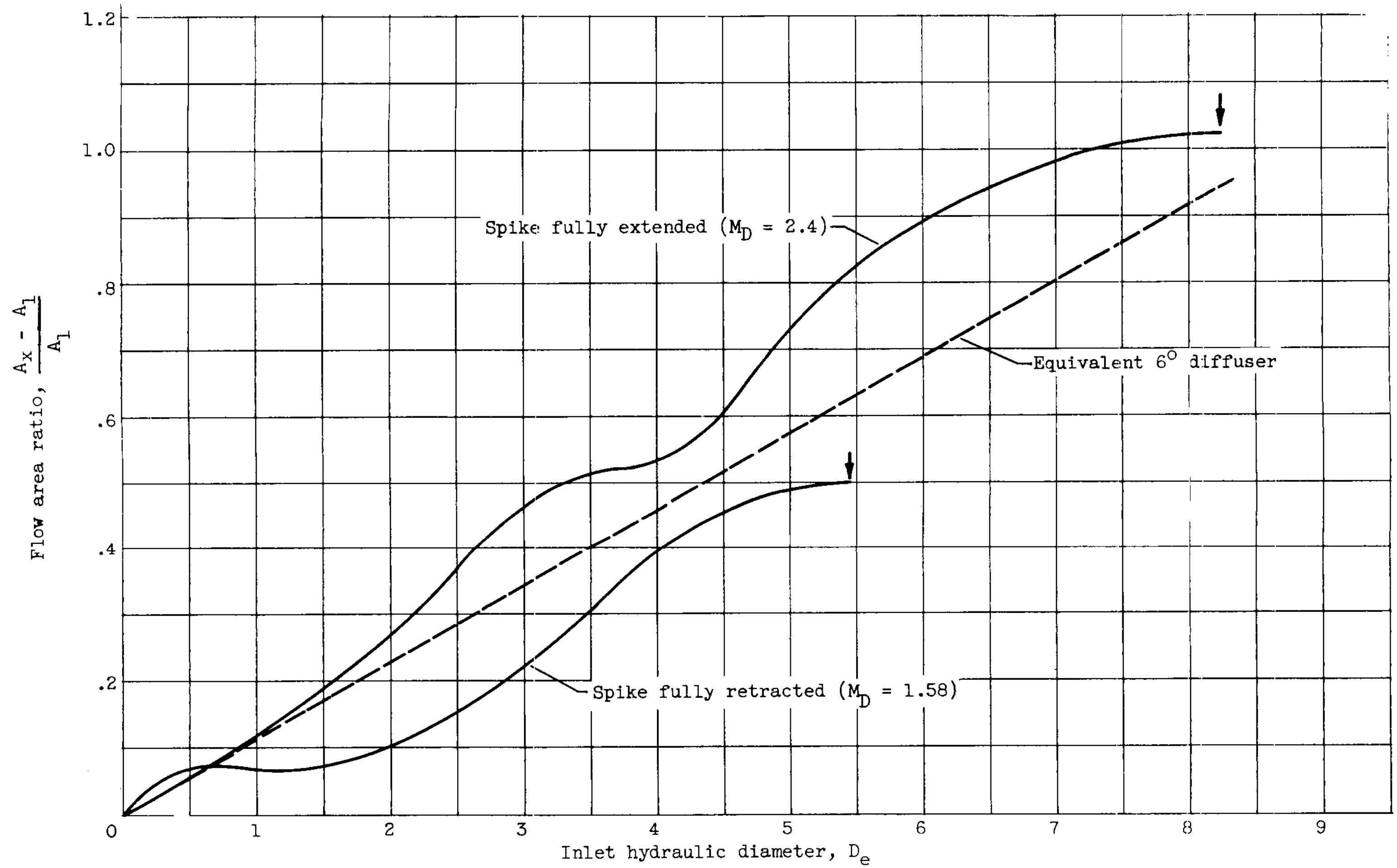
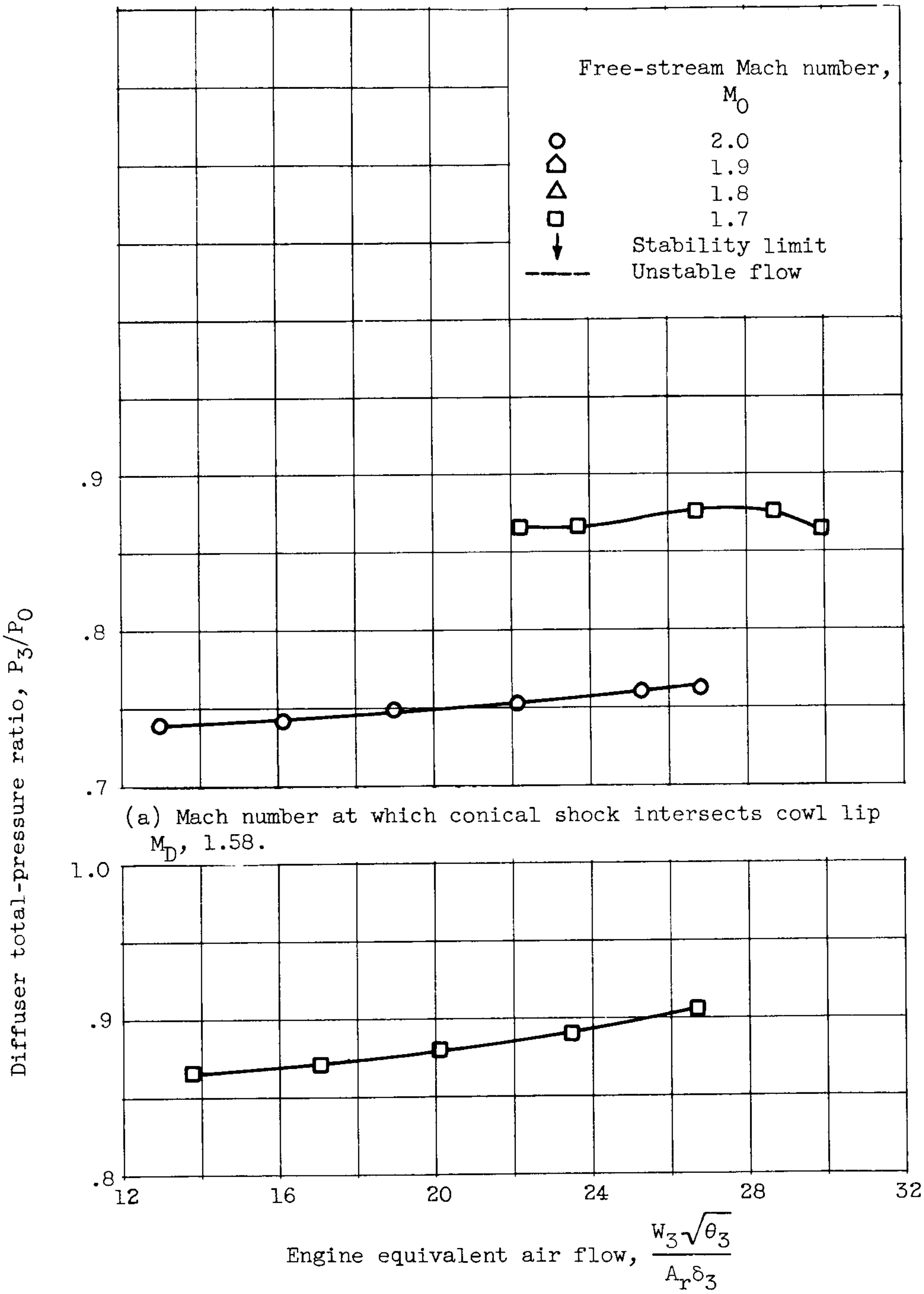


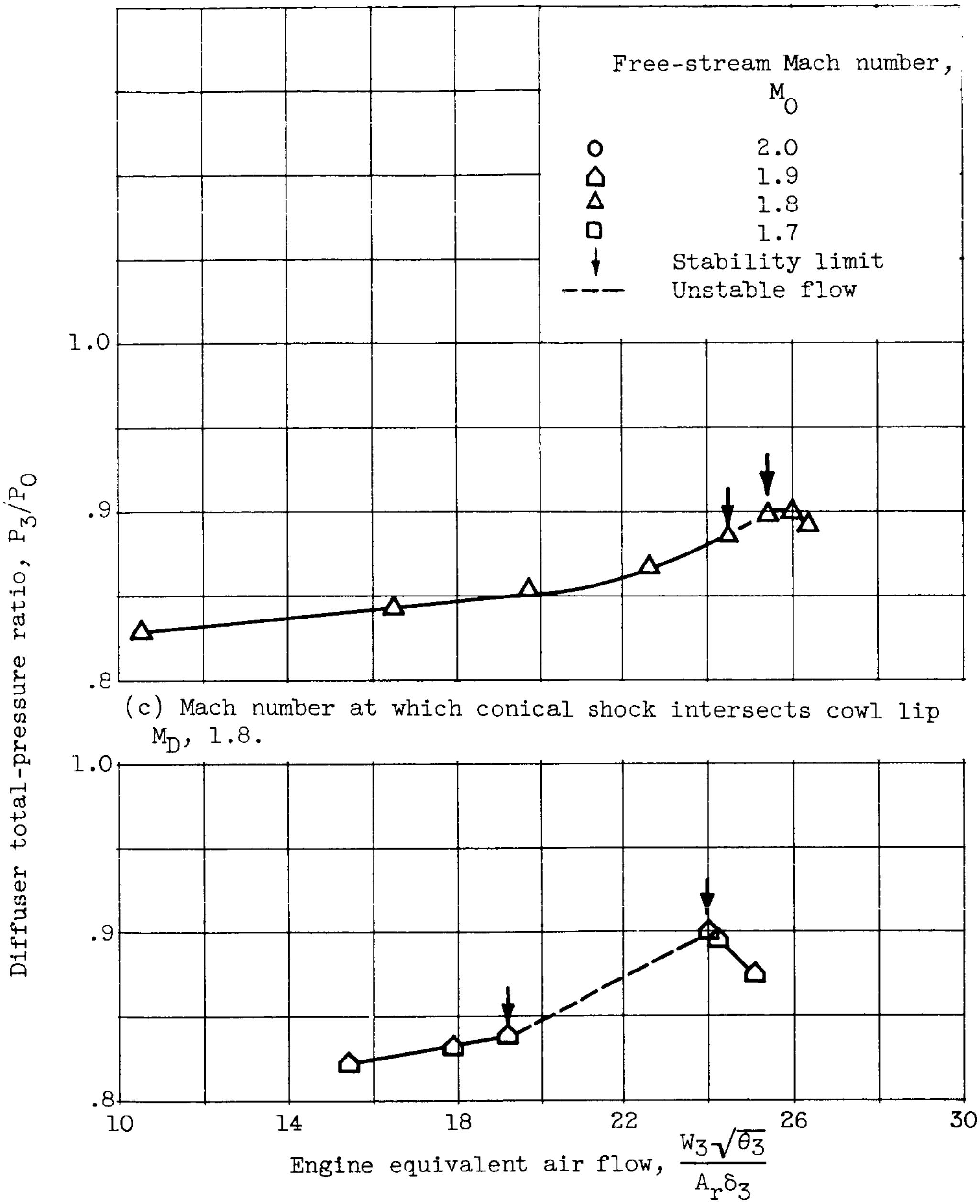
Figure 2. - Diffuser area variation for two spike positions. M_D, Mach number at which oblique shock intersects cowl lip; arrow indicates compressor face.



(a) Mach number at which conical shock intersects cowl lip M_D, 1.58.

(b) Mach number at which conical shock intersects cowl lip M_D, 1.7.

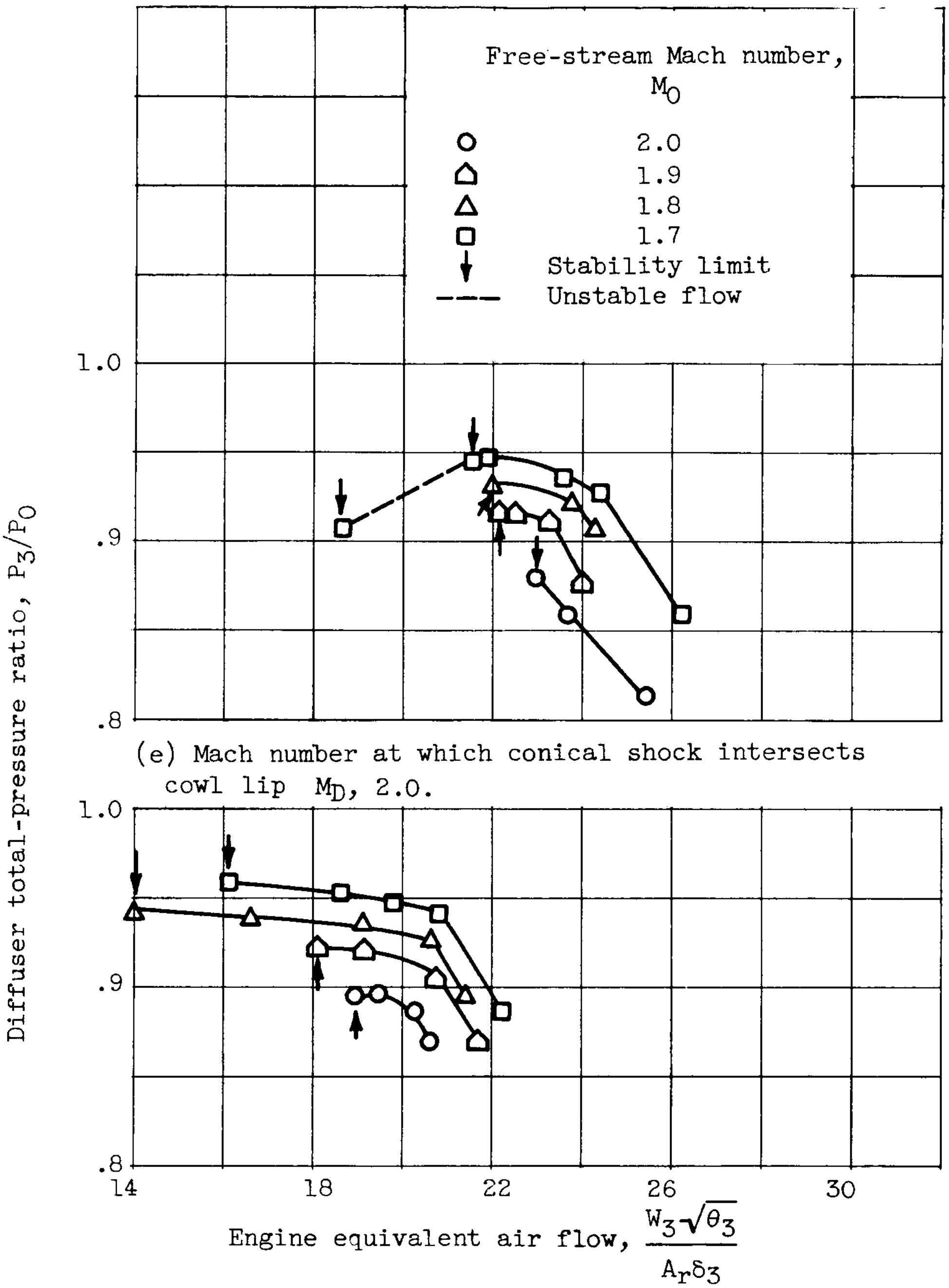
Figure 3. - Diffuser performance with choked plug; bypass closed.



(c) Mach number at which conical shock intersects cowl lip M_D, 1.8.

(d) Mach number at which conical shock intersects cowl lip M_D, 1.9.

Figure 3. - Continued. Diffuser performance with choked plug; bypass closed.



(f) Mach number at which conical shock intersects cowl lip M_D, 2.4.

Figure 3. - Concluded. Diffuser performance with choked plug; by pass closed.

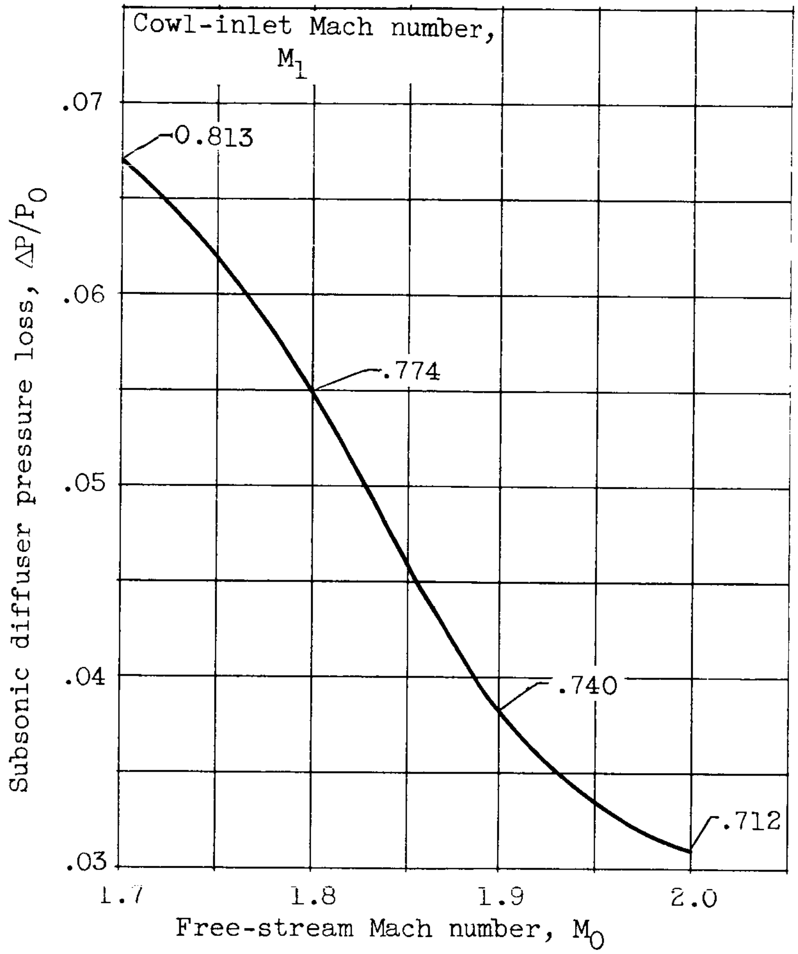
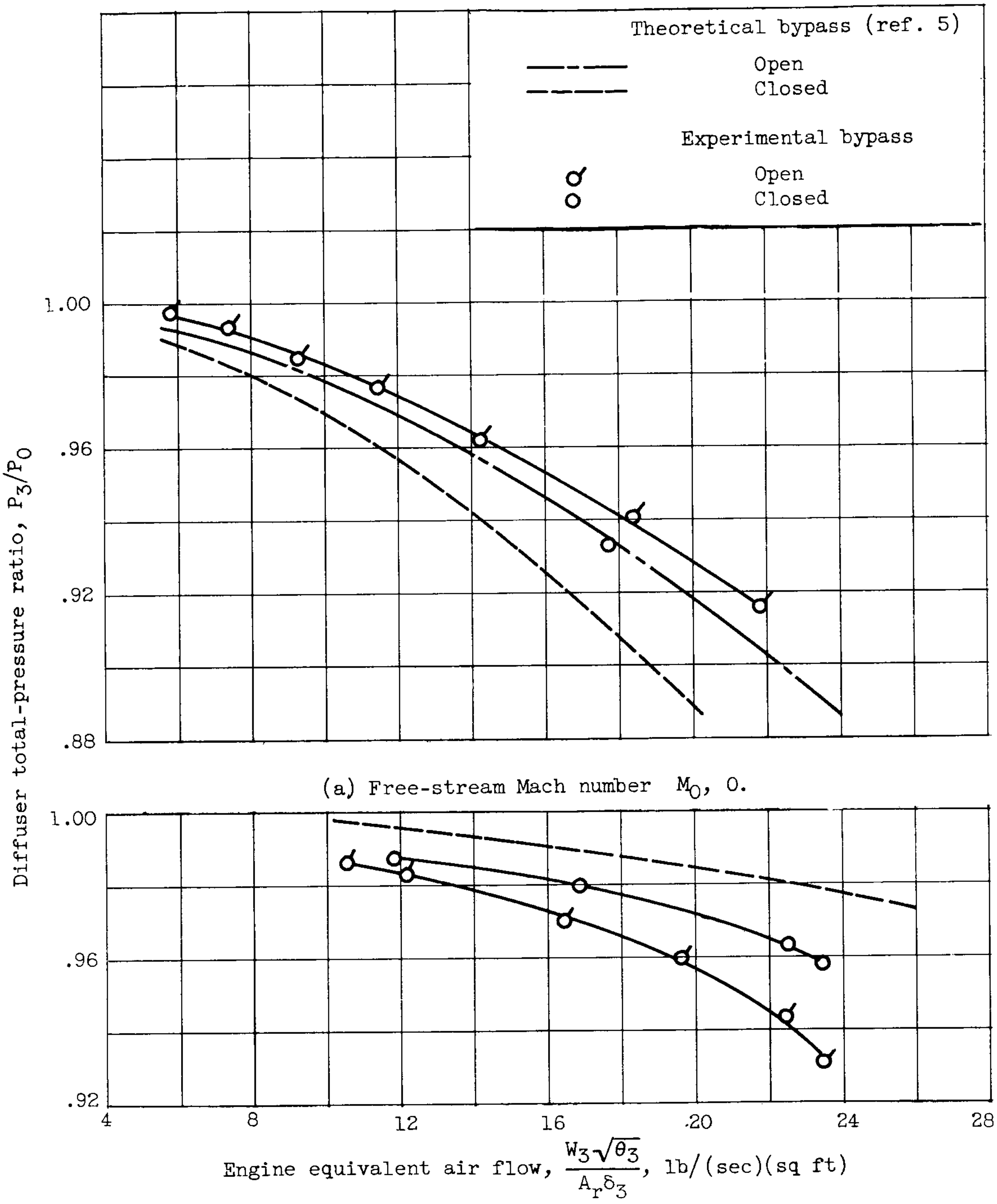
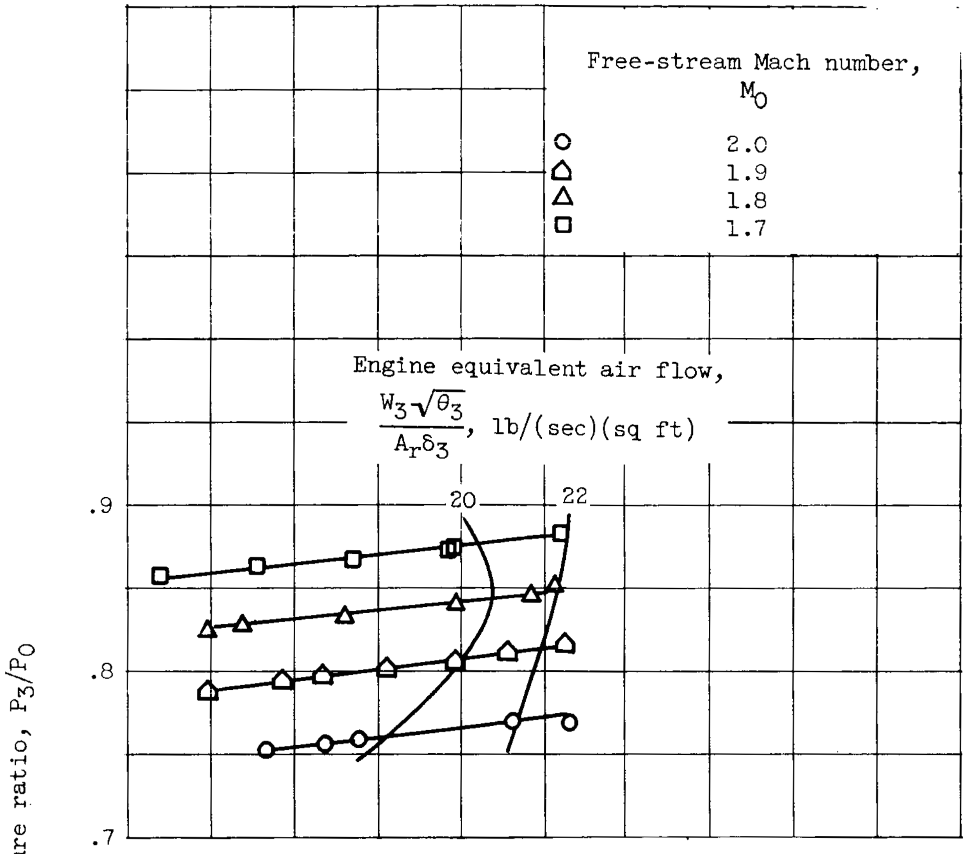


Figure 4. - Performance of subsonic diffuser for critical air flow. Mach number at which conical shock intersects cowl lip $M_D = M_0$.

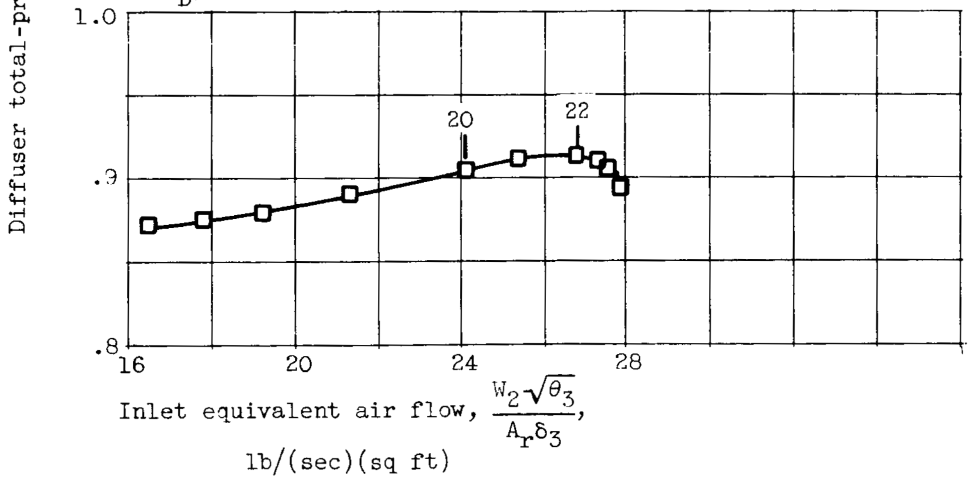


(b) Free-stream Mach number M_0, 0.6.

Figure 5. - Subsonic performance of diffuser with engine. Mach number at which conical shock intersects cowl lip M_D, 1.58.

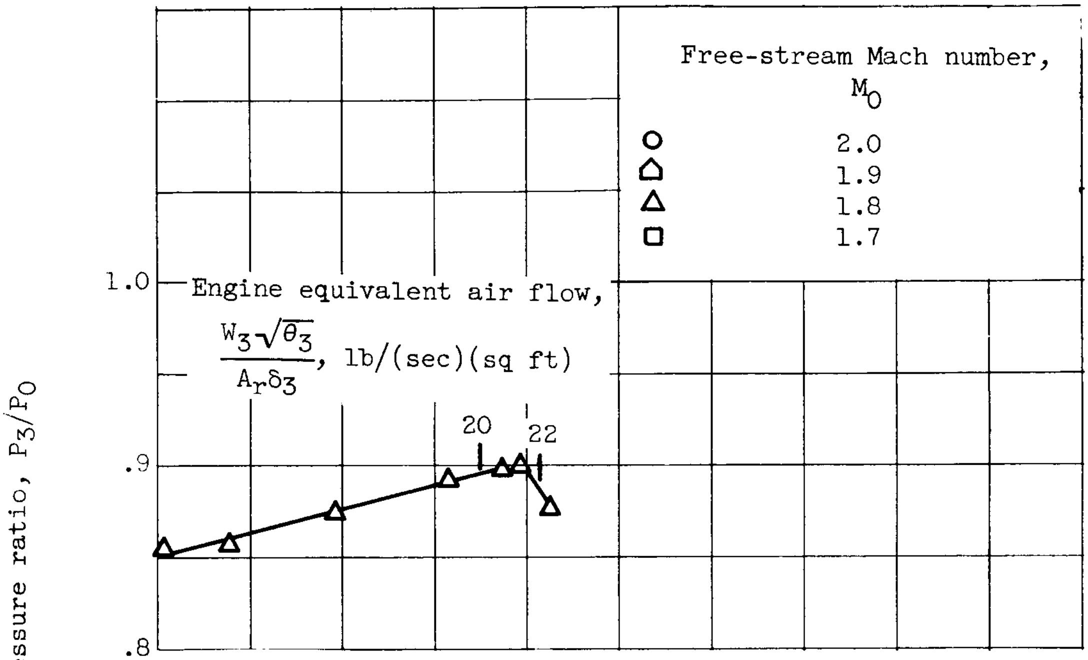


(a) Mach number at which conical shock intersects cowl lip M_D, 1.58.

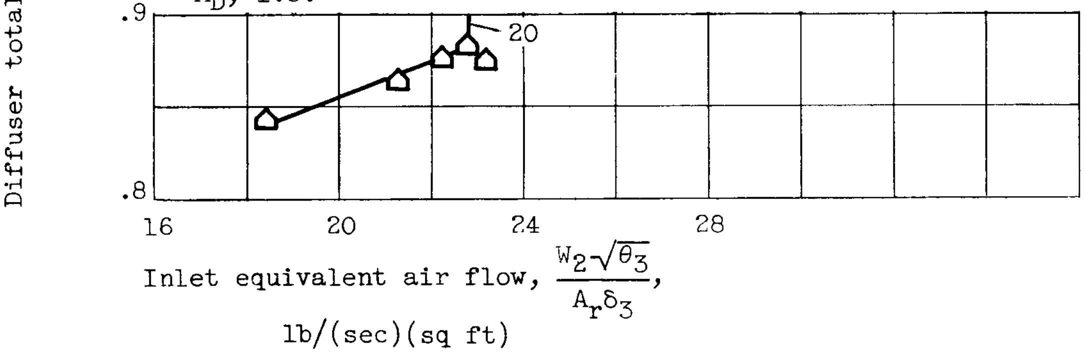


(b) Mach number at which conical shock intersects cowl lip M_D, 1.7.

Figure 6. - Diffuser performance with engine; bypass open.

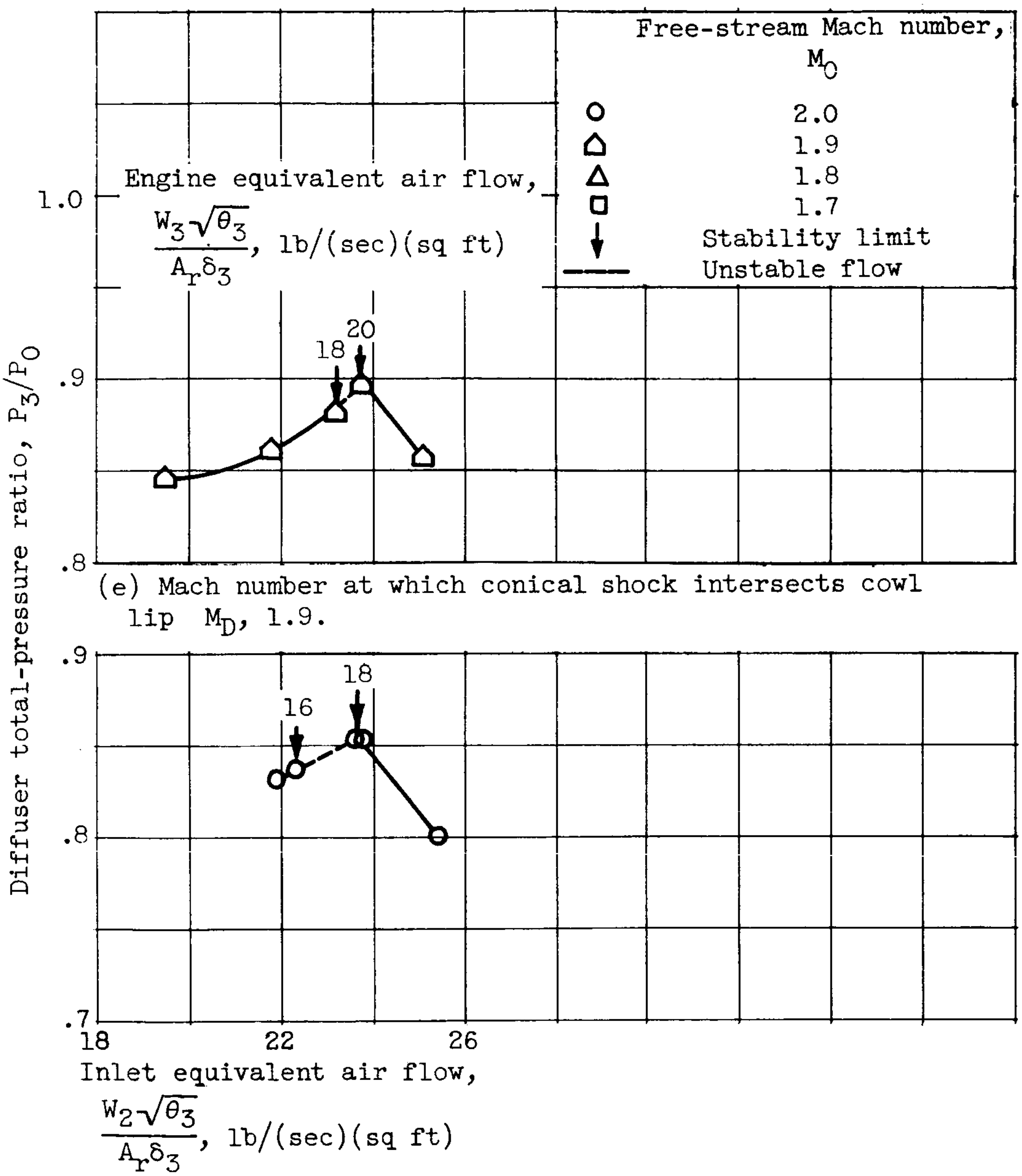


(c) Mach number at which conical shock intersects cowl lip M_D, 1.8.



(d) Mach number at which conical shock intersects cowl lip M_D, 1.86.

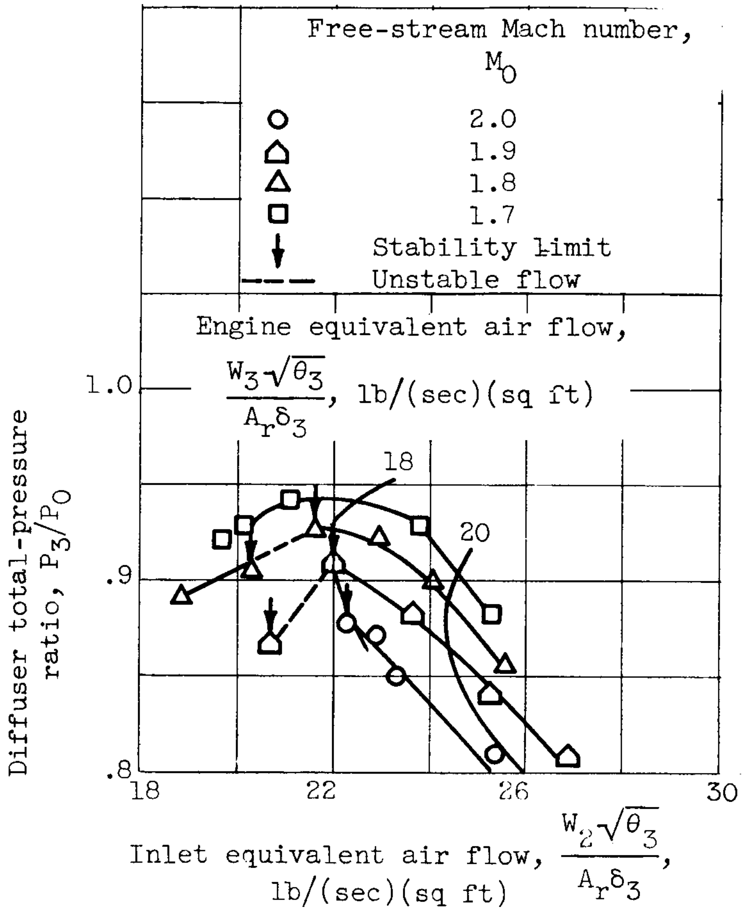
Figure 6. - Continued. Diffuser performance with engine; bypass open.



(e) Mach number at which conical shock intersects cowl lip M_D, 1.9.

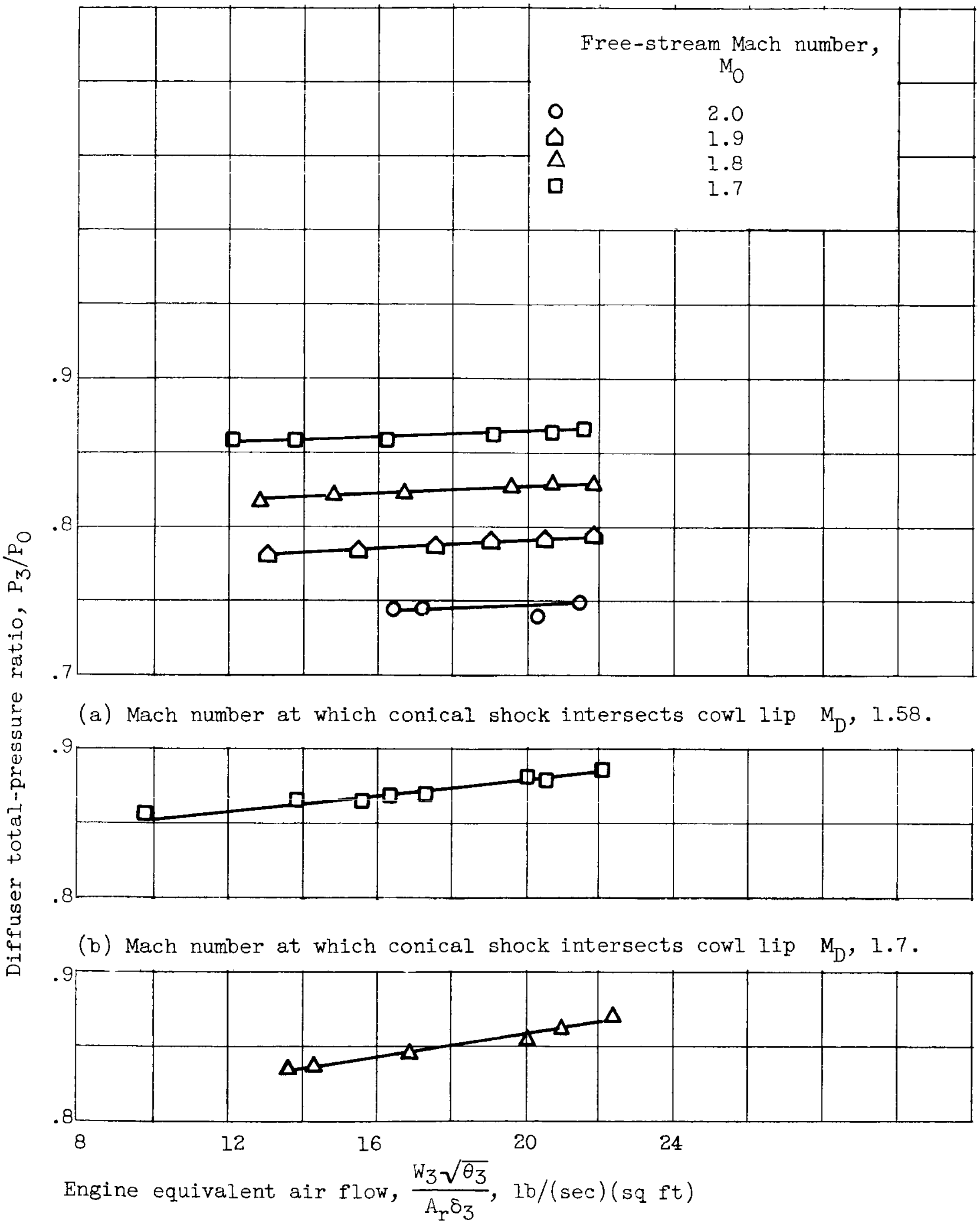
(f) Mach number at which conical shock intersects cowl lip M_D, 1.92.

Figure 6. - Continued. Diffuser performance with engine; bypass open.



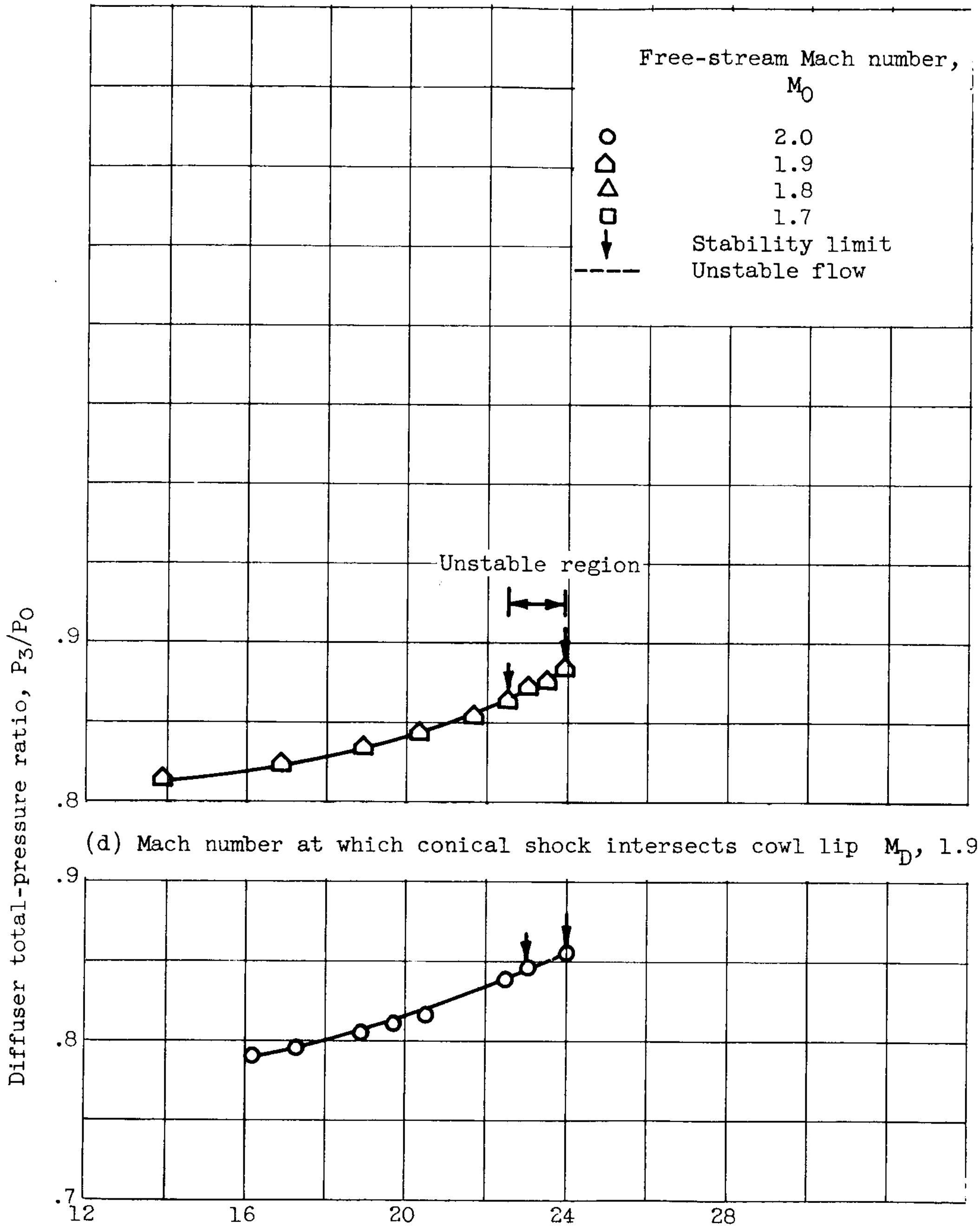
(g) Mach number at which conical shock intersects cowl lip M_D, 2.0.

Figure 6. - Concluded. Diffuser performance with engine; bypass open.



(c) Mach number at which conical shock intersects cowl lip M_D, 1.8.

Figure 7. Diffuser performance with engine; bypass closed.

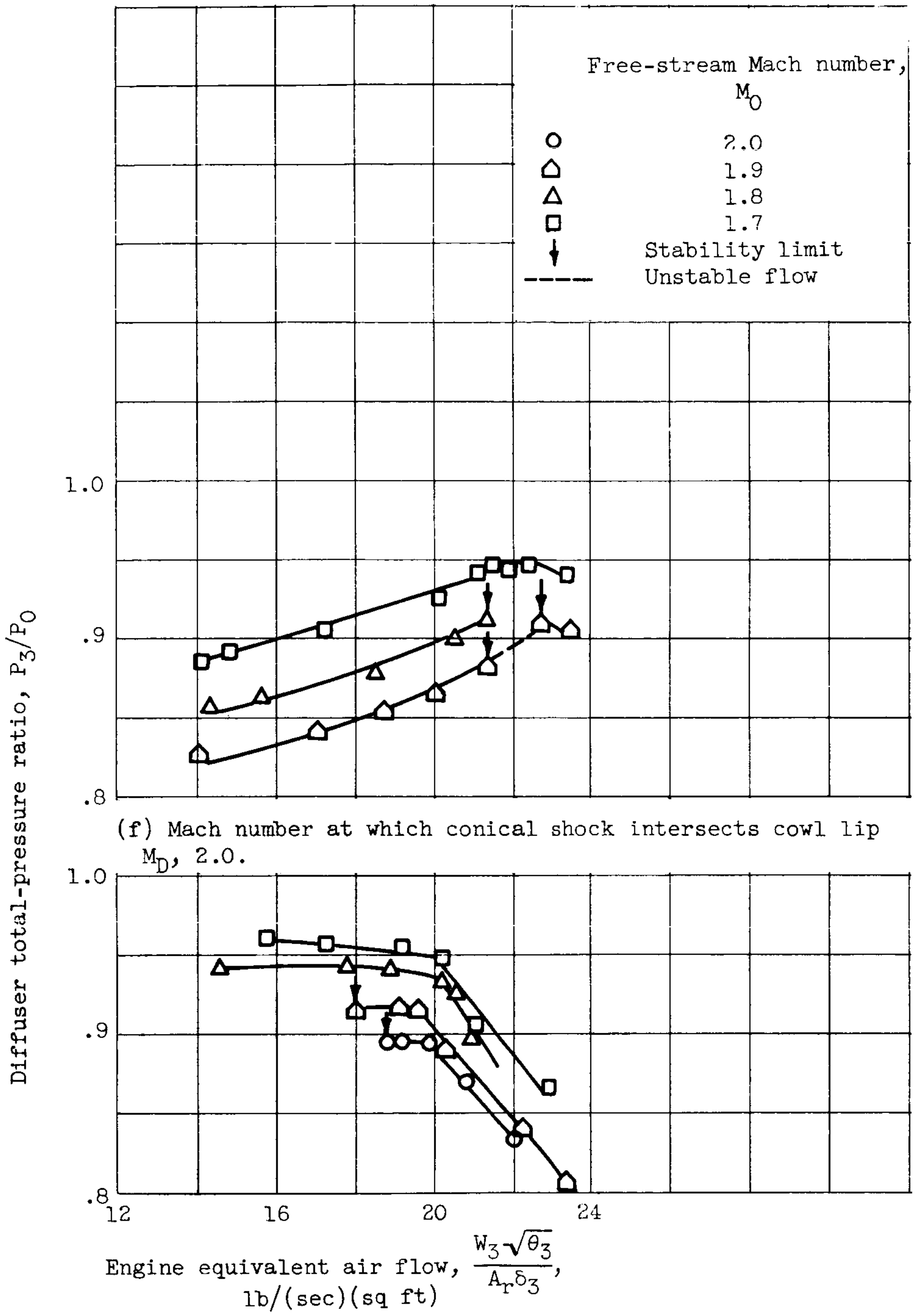


(d) Mach number at which conical shock intersects cowl lip M_D, 1.9.

Engine equivalent air flow, $\frac{W_3\sqrt{\theta_3}}{A_r\delta_3}$, lb/(sec)(sq ft)

(e) Mach number at which conical shock intersects cowl lip M_D, 1.92.

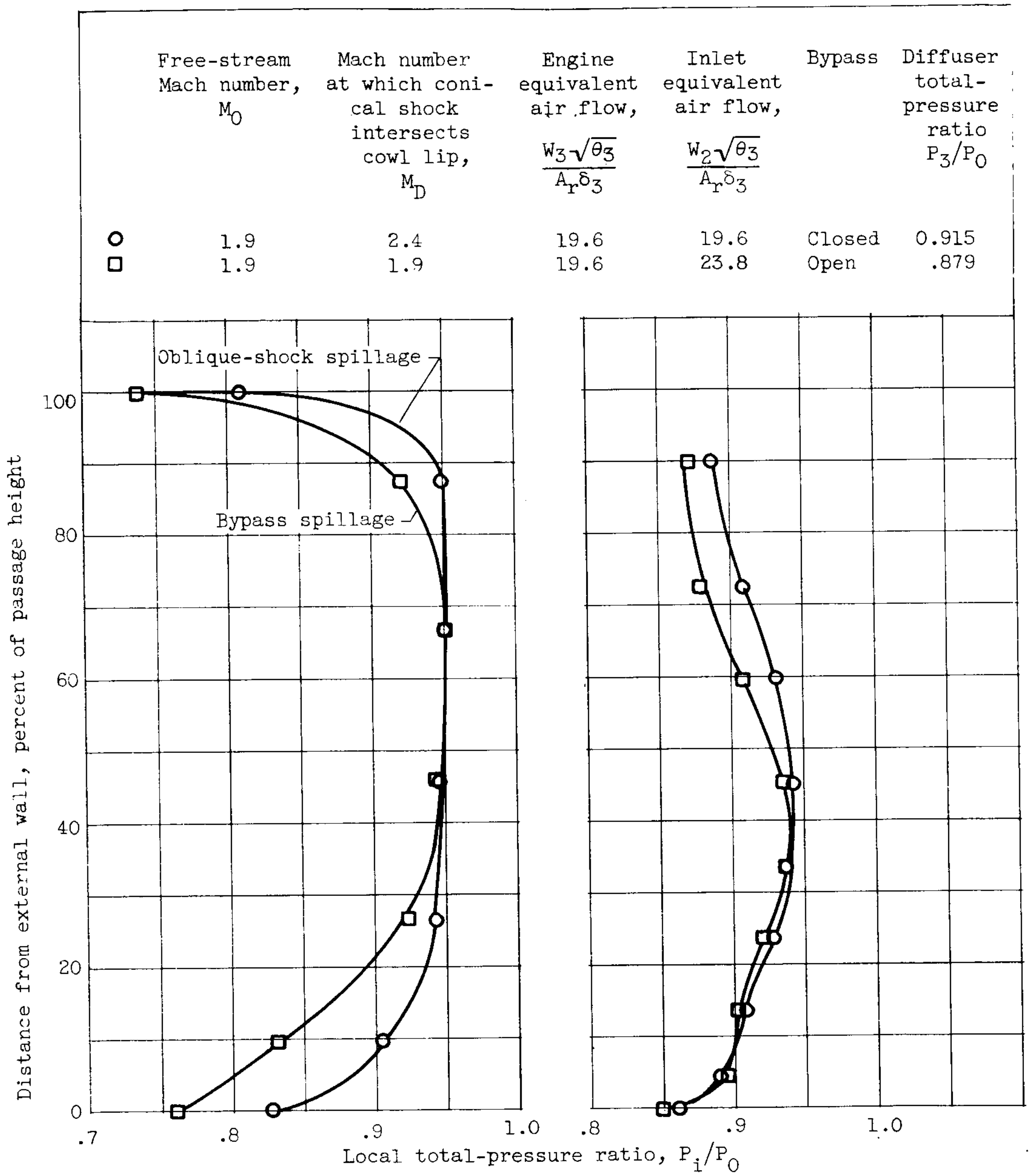
Figure 7. - Continued. Diffuser performance with engine; bypass closed.



(f) Mach number at which conical shock intersects cowl lip M_D, 2.0.

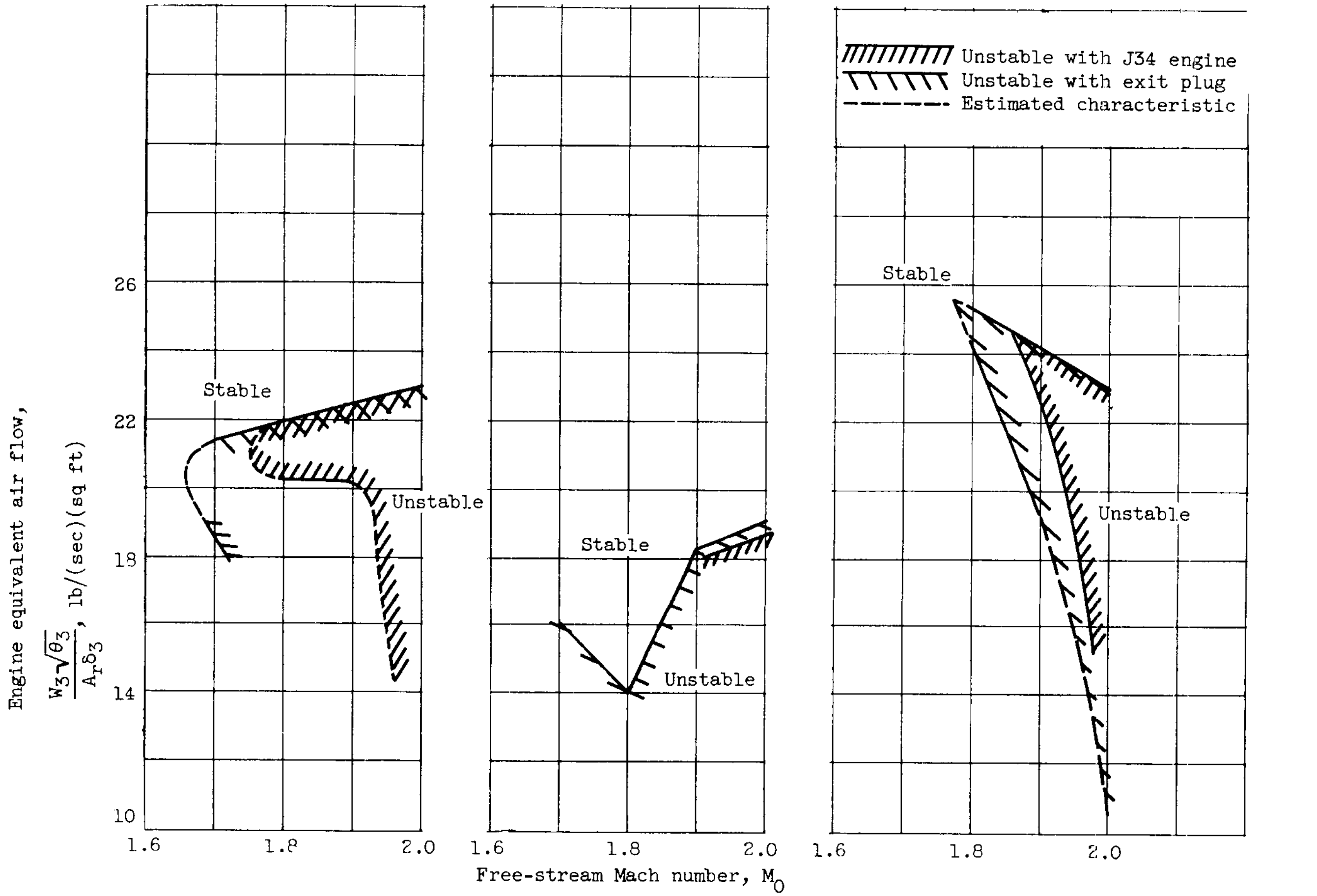
(g) Mach number at which conical shock intersects cowl lip M_D, 2.4.

Figure 7. - Concluded. Diffuser performance with engine; bypass closed.



(a) Ahead of bypass (station 2). (b) Compressor face (station 3).

Figure 8. - Effect of spillage mechanism on diffuser profiles.



(a) Mach number at which conical shock intersects cowl lip M_D, 2.0.

(b) Mach number at which conical shock intersects cowl lip M_D, 2.4.

(c) Mach number at which conical shock intersects cowl lip M_D, M_0.

Figure 9. - Stable air flow range for various spike positions.

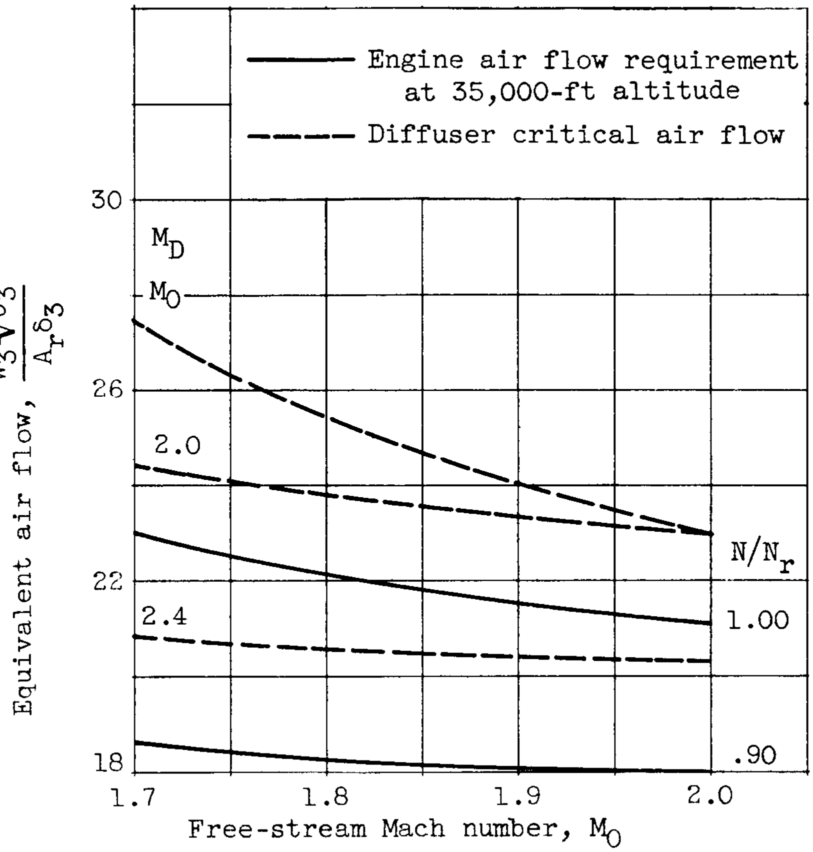


Figure 10. - Translating-spike air flow regulation. M_D, Mach number at which conical shock intersects cowl lip; N/N_r, ratio of engine rotative speed to rated speed.

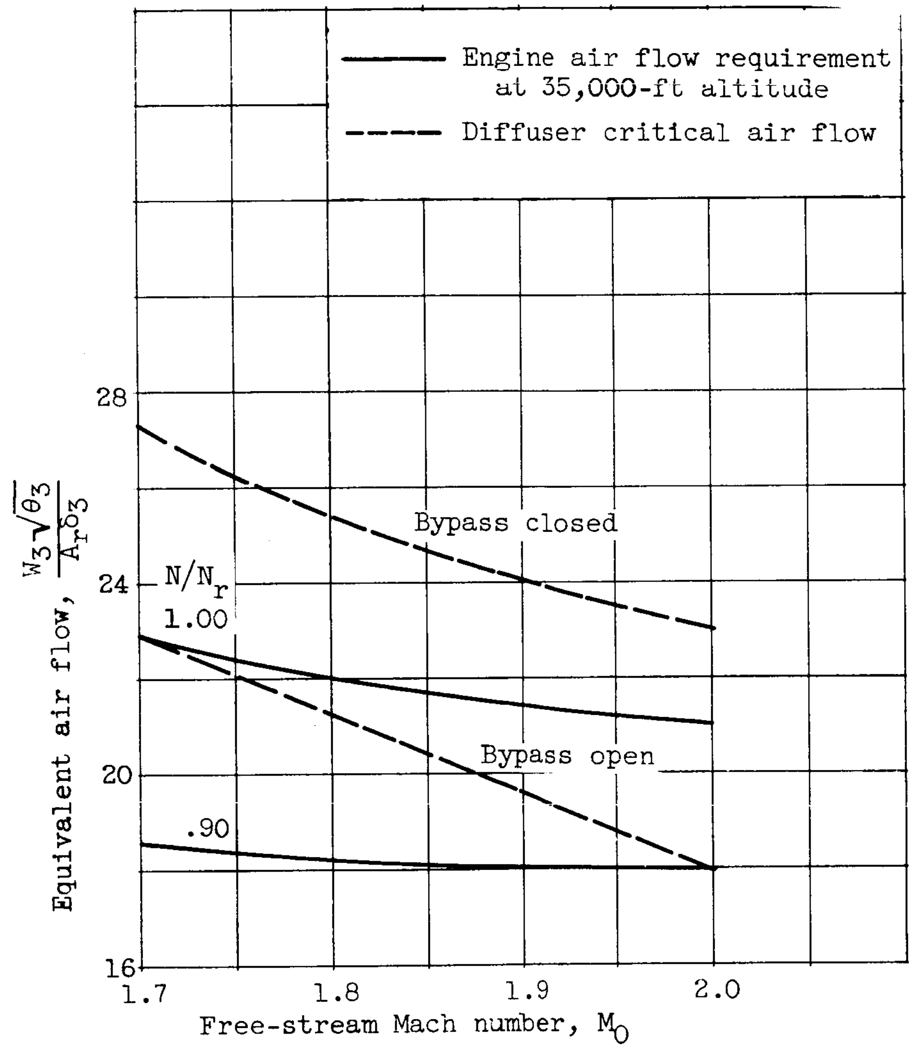


Figure 11. - Bypass air flow regulation. Mach number at which conical shock intersects cowl lip $M_D = M_0$; N/N_r, ratio of engine rotative speed to rated speed.

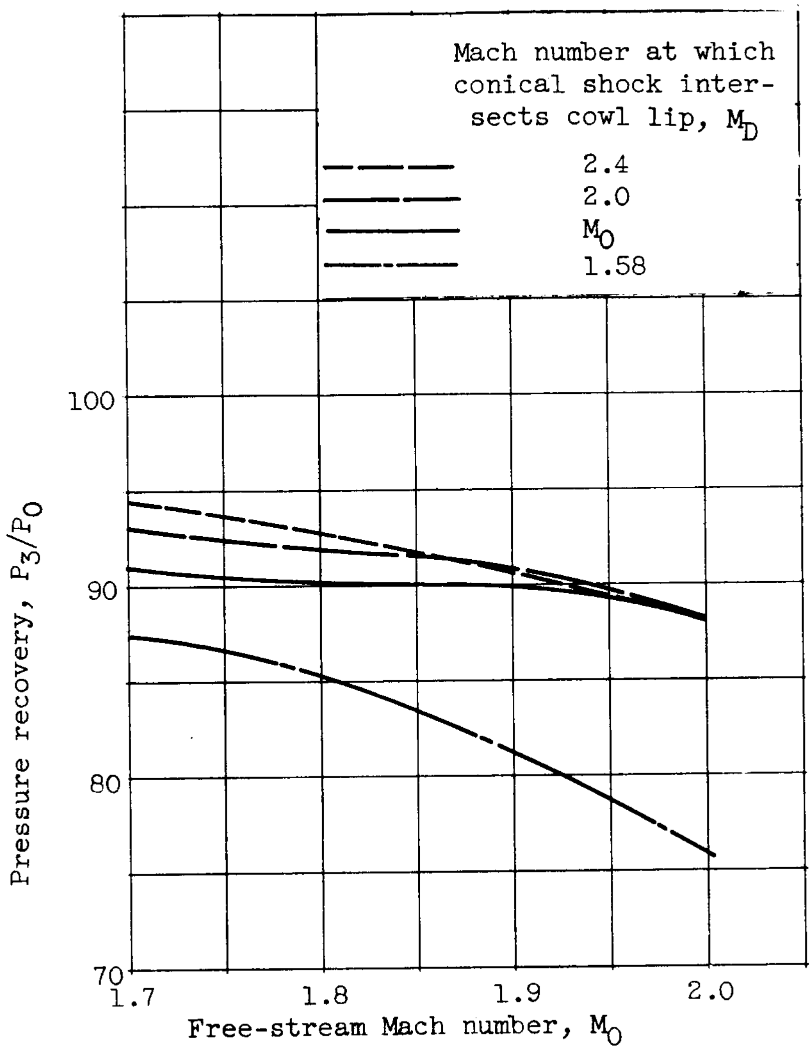


Figure 12. - Variation of diffuser pressure recovery at critical air flow.